AD NUMBER
AD864827
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; FEB 1970. Other requests shall be referred to Arnold Engineering Development Center, Arnold AFB, TN.**
AUTHORITY
AEDC ltr 22 Sep 1975

AEDC-TR-70-7

Copy 1

EVALUATION OF THE OVERALL ROOT-MEAN-SQUARE FLUCTUATING PRESSURE LEVELS IN THE AEDC PWT 16-FT TRANSONIC TUNNEL

O. P. Credle and T. O. Shadow

ARO, Inc.

February 1970

~~This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of Arnold Engineering Development Center (AETS), Arnold Air Force Station, Tennessee 37389.~~

PROPULSION WIND TUNNEL FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

EVALUATION OF THE OVERALL ROOT-MEAN-SQUARE FLUCTUATING PRESSURE LEVELS IN THE AEDC PWT 16-FT TRANSONIC TUNNEL

O. P. Credle and T. O. Shadow
ARO, Inc.

FOREWORD

The work reported herein was done at the request of the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC), under System 921E.

The test results presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract F40600-69-C-0001. The work was conducted under ARO Project No. PB1963 from September 9 to 10, 1969, and the manuscript was submitted for publication on December 5, 1969.

Information in this report is embargoed under the Department of State International Traffic in Arms Regulations. This report may be released to foreign governments by departments or agencies of the U. S. Government subject to approval of Arnold Engineering Development Center (AETS), or higher authority within the Department of the Air Force. Private individuals or firms require a Department of State export license.

This technical report has been reviewed and is approved.

George F. Garey	Roy R. Croy, Jr.
Lt Colonel, USAF	Colonel, USAF
AF Representative, PWT	Director of Test
Directorate of Test	

ABSTRACT

An investigation was conducted to evaluate the fluctuating pressures in the AEDC PWT 16-ft transonic wind tunnel circuit. Test results were obtained over a Mach number range from 0.6 to 1.3 and a unit Reynolds number range from 1.8 to 6.8 million. The influence of Mach number, total pressure, total temperature, and (auxiliary) plenum suction on the test section fluctuating pressures was determined. In addition, a comparison of the Tunnel 16T fluctuating pressures with those of the AEDC PWT 4-ft transonic tunnel and the NASA-Huntsville 14-in. transonic tunnel is made. A critical Mach number range was defined near a Mach number of 0.75. The maximum root-mean-square fluctuating pressure in the test section was 3.5 percent of the free-stream dynamic pressure in the critical Mach number range. The source of this maximum fluctuating pressure did not appear to be controlled by the compressor. The free-stream fluctuating pressure was found to vary inversely with the total pressure and to be relatively invariant with total temperature and auxiliary plenum suction.

CONTENTS

APPENDIX

Illustrations

NOMENCLATURE

a	Speed of sound, ft/sec
ΔC_p	Fluctuating pressure parameter, $\left[\sqrt{\overline{p^2(t)}}\,/q_\infty\right]$ x 100 percent
f	Frequency, Hz
Δf	Analyzer bandwidth, Hz
G(f)	Power-spectral-density function, psf^2-sec
L_p	Sound pressure level, db (Ref. 0.002 dynes/cm^2)
M_∞	Free-stream Mach number
p(t)	Instantaneous fluctuating pressure, psf
$\sqrt{\overline{p^2(t)}}$	Root-mean-square fluctuating pressure, psf
p_s	Free-stream static pressure, psfa
p_t	Total pressure, psfa
q_∞	Test section free-stream dynamic pressure, psf
Re/ft	Reynolds number per foot
T_t	Total temperature, °F
t	Time, sec

W_a/W_t	Ratio of plenum weight flow to tunnel weight flow
X	Cone station from tip, in.
τ	Wall porosity, percent open

SECTION I
INTRODUCTION

An evaluation of the fluctuating pressures in the Propulsion Wind Tunnel, Transonic (16T) of the Propulsion Wind Tunnel Facility (PWT) has been conducted. The objective of the evaluation was to determine the influence of Mach number, total pressure, temperature, and auxiliary plenum suction on the test section fluctuating pressure levels. Previous investigations in Tunnel 16T (Refs. 1 and 2) were limited to measurements at select locations in the test section region only. The present investigation included measurements in the test section and around the entire tunnel circuit as well. In addition, the test section region was more extensively instrumented for the present study. Sufficient data were also obtained to make a direct comparison of the fluctuating pressure environment in Tunnel 16T with that in the Propulsion Wind Tunnel, Transonic (4T) (Ref. 3) and in the NASA-Huntsville 14-in. tunnel (Ref. 4).

A 10-deg cone with microphones and transducers was used to measure the fluctuating pressures in the region of the test section centerline. Additional microphones were located on the test section wall, around the tunnel circuit, and in the compressor region. Tunnel conditions were varied over a Mach number range from 0.60 to 1.30 and a unit Reynolds number range from 1.8 to 6.8 million.

This report presents the results of this investigation in the form of the measured overall root-mean-square (rms) levels as a function of Mach number, total pressure, total temperature, and plenum weight flow.

SECTION II
APPARATUS

2.1 TUNNEL 16T DESCRIPTION

Tunnel 16T is a variable density, continuous flow wind tunnel. The test section is 16 ft square by 40 ft long and enclosed by perforated walls of fixed six-percent porosity. The perforated walls allow continuous operation through the Mach number range from 0.20 to 1.60 with minimum wall interference. A section of the perforated walls and the geometry details of the holes are shown in Fig. 1 (Appendix). A more complete description of the tunnel may be found in Ref. 5.

2.2 CALIBRATION BODY

The free-stream centerline fluctuating pressures were measured with an instrumented 10-deg cone shown installed in the test section in Fig. 2. The cone was instrumented with three different types of pressure transducers or microphones: Kulite model CPL-070-4 with a frequency response from 20 Hz to 10 kHz, Schaevitz-Bytrex model HFD with a frequency response from 0 to 4 kHz, and Kistler model 601L with a frequency response from 100 Hz to 100 kHz. The cone had symmetrical longitudinal flats which were machined on the top and bottom areas of the cone to allow for flush mounting the transducers. The included angle between the symmetrical flats was 9.24 deg. The geometry details of the 10-deg cone and the location of the transducers are shown in Fig. 3. The various mounting arrangements for the transducers are shown in Fig. 4.

The 10-deg cone has become the standard calibration body in PWT for the evaluation of wind tunnel disturbances. Although it is recognized that aerodynamically a more slender body is preferred, a 10-deg cone is about the minimum angle that will allow the installation of instrumentation in the interior of the cone. A previous study in the PWT Tunnel 16T (Ref. 2) plus studies in the PWT Tunnel 4T (Ref. 3) and in the NASA-Huntsville 14-in. tunnel (Ref. 4) were all conducted using a 10-deg cone of identical geometry. Thus, comparative data between wind tunnels are now available.

2.3 INSTRUMENTATION

In addition to the previously discussed instrumented 10-deg cone, the test section wall, the plenum chamber, the tunnel circuit, and the compressor were instrumented with Kistler model 601L 0.25-in. microphones, as shown in Fig. 5. A tabulation of the location of transducers throughout the tunnel circuit is included in Fig. 5. The manufacturer's specified frequency response is from 100 Hz to 100 kHz. The mounting arrangement for all microphones, exclusive of those on the cone, is shown in Fig. 6. The tunnel circuit and compressor microphones were flush mounted on the bottom portion of the tunnel shell. The mount was electrically isolated from the shell to minimize 60-Hz pickup. A flush-mounted microphone was also located in the compressor discharge nacelle. The test section wall microphone was positioned in the center of a locally solid region of the wall by filling and sanding smooth a radius of porous holes around the microphone. The radius was approximately 40 microphone diameters. This installation technique precluded the measurement of purely near-field influence of the most adjacent

upstream hole and allowed for the measurement of what might be considered as the radially integrated average value of pressure fluctuations at the wall surface.

The buried microphone (Fig. 6) was included for the evaluation of the structureborne vibration environment at each measurement location. It was determined, however, that the buried microphone was not acoustically isolated and thus could not be considered as having a structureborne vibration-induced output only.

All microphones and pressure transducers were calibrated with a reference sound-pressure-level (L_p) of 160 db at 1000 Hz. The standard for this calibration is directly traceable to the National Bureau of Standards. The output of all channels was recorded on a multiplexed, FM magnetic tape system for future analysis. The frequency passband of the tape system was from 0 Hz to 7.5 kHz, and this established the upper frequency limit for the data acquisition system. All channels were monitored with an oscilloscope and headset during the test. In addition, selected channels were analyzed on line using a digital real time power-spectral-density analyzer. The output of this analyzer was displayed on a cathode ray tube (CRT).

SECTION III
TEST DESCRIPTION

3.1 TUNNEL OPERATING CONDITIONS

The stated objectives of the subject investigation were achieved by carefully selecting and judiciously varying the tunnel operating conditions. In so far as was possible, the tunnel conditions were varied so that the influence of a single parameter could be isolated. The variation of Reynolds number with Mach number, total pressure, and temperature is presented in Fig. 7. The tunnel background noise levels were measured during wind-off runs before the test and were found to be low enough to be neglected.

3.2 DATA REDUCTION

The on-line data reduction included a tabulation of the tunnel conditions and of 12 channels of overall rms measurements. The output of 12 selected microphones was integrated, then averaged with a 2.5-sec time constant network and converted to a direct current (dc)

magnitude using PWT-designed rms to dc converters. The analog output of the converters was then digitized using the conventional tunnel data acquisition system. The passband for the on-line overall rms measurements was equal to that of the selected microphone and transducer channels alone.

The off-line data reduction consisted of the determination of the overall rms levels recorded on magnetic tape. The passband for the off-line analysis was limited by the tape system to 0 to 7.5 kHz. A comparison of the on-line and off-line data levels from the same test point reveals a difference of less than 10 percent. This indicates that the energy spectra was concentrated in the 0- to 7.5-kHz region, a fact that was verified by the on-line digital spectrum analyzer.

The amplitude scale of the rms pressure levels is given in terms of the fluctuating pressure parameter (ΔC_p), in percent, of q_∞ and defined as:

$$\Delta C_p = \left[\sqrt{\overline{p^2(t)}}/q_\infty\right] \times 100 \qquad (1)$$

where the overbar represents the time average, and q_∞ is the average value of the test section free-stream dynamic pressure.

When the 10-deg cone is exposed to a moving medium, a pressure gradient develops on the surface of the cone, and the transducers are thus influenced by both the static and the total pressures. If the medium is at rest, however, or the cone moves with the medium, then the true static pressure (p_s) and acoustic pressure ($p(t)$) are measured. Thus the 10-deg cone data should be corrected for the total pressure effects and the pressure distribution on the cone. Such a correction would determine the true acoustic pressure and also allow the comparison of data from different angle cones. The need for such a correction to the data is discussed in Ref. 6. However, since the data presented from the previous studies were not corrected and it is intended to compare these data with the present data, a correction factor has not been applied to the 10-deg cone levels.

3.3 PRECISION OF MEASUREMENTS

The estimated errors in the steady-state, tunnel condition data as a result of instrumentation and calibration inaccuracies are as follows:

$$M_\infty = \pm 0.003 \; (0.6 < M_\infty \; 1.1)$$
$$\pm 0.010 \; (M_\infty > 1.1)$$
$$q_\infty = \pm 4 \text{ psf}$$

The accuracy of the fluctuating pressure data as a result of instrumentation and calibration errors is estimated for the microphones to be limited to ±0.4 db in absolute value.

SECTION IV
RESULTS AND DISCUSSION

The data presented in this report are representative of the Tunnel 16T environment and are intended to reveal the influence of the various wind tunnel parameters on the overall rms ΔC_p levels in the test section free stream. The discussion of the data will emphasize how the Tunnel 16T ΔC_p characteristics vary rather than why. Data points are connected with straight lines to indicate the grouping of the same set only.

The variation of the pressure parameter (ΔC_p) with Mach number at various tunnel locations is shown in Fig. 8. The levels and trends in the test section free stream as measured on the 10-deg cone are in agreement with the values reported in Ref. 2. The maximum value of ΔC_p at $M_\infty = 0.75$ is known from Ref. 2 to be caused by a very high level disturbance at a frequency of 570 Hz. The level of this maximum diminishes on either side of $M_\infty = 0.75$, but the frequency is invariant. A comparison of the trends at the other tunnel locations reveals that the maximum at $M_\infty = 0.75$ is detected on the 10-deg cone only. There is a maximum detected on the test section wall, but at a reduced Mach number of 0.65. Note in particular that there is an absence of a maximum in the stilling chamber (eliminating a possible upstream source). Based on these data, it appears that the disturbance at $M_\infty \approx 0.75$ originates in the test section region. A comparison of the test section and compressor level values is shown in Fig. 9. Note that the compressor level is increasing with Mach number at $M_\infty \geq 0.75$, whereas the test section level is decreasing. The disturbance could be in the form of an aero-acoustic resonance with an upstream forcing function, but this has not been established at this time. For the present report, a critical Mach number range with respect to fluctuating dynamic pressure levels is defined as $0.70 \leq M_\infty \leq 0.80$.

The effect of total pressure is one of decreasing levels of ΔC_p with increasing pressure, as shown in Fig. 10. This trend is consistent at all Mach numbers, even in the critical Mach number range. Note that a maximum in ΔC_p of 3.5 percent occurs at the minimum total pressure and that the rate of change of ΔC_p with total pressure is greatest below atmospheric pressure. Note also that the same trends are indicated at all measurement locations.

The variation of ΔC_p as a function of unit Reynolds number is shown in Fig. 11. This variation was measured by transducer 8 on the 10-deg cone. The introduction of a body in an airstream to evaluate the effects of Reynolds number on the fluctuating dynamic pressures requires that the transition Reynolds number of that body in the airflow be considered. The aft-most transducer was selected for the evaluation to best ensure that the comparative data were all obtained behind the transition point on the 10-deg cone. It was determined in Ref. 2, however, and confirmed during the present evaluation, that the levels of ΔC_p did not vary significantly from the front to the back of the cone. This fact is demonstrated in Fig. 12 for ten different Mach numbers. The variation that is indicated is about the same in all cases and is attributed to the influence of small disturbances from the forward transducers on the aft ones and the fact that the two forward transducers (Fig. 3) had a more narrow frequency bandwidth than the two aft ones. In addition, the 10-deg cone measurements were not corrected for cone surface pressure gradient effects, as discussed in Section 3.2. Finally, it is believed that the level of the free-stream pressure fluctuations was sufficient to mask the near-field pressure fluctuation effects on the cone, and thus the true but uncorrected free-stream levels were measured.

The use of auxiliary plenum suction to remove air from the test section through the perforated walls requires that a separate or external compressor system be used. This system is known as the Plenum Evacuation System (PES) and represents a potential source of energy that could contribute to disturbances in the test section. At the same time, it is also possible that the use of auxiliary plenum suction could improve the flow quality in the test section and thus reduce the disturbances in the test section. It was found in Ref. 3, for instance, that the use of auxiliary plenum suction for $0.40 < M_\infty < 0.60$ reduced the random noise levels. In this report, auxiliary plenum suction is measured by the fractional weight flow parameter (W_a/W_t). The results of the evaluation of Tunnel 16T are shown in Fig. 13. Note that for $M_\infty > 0.90$, the levels of ΔC_p are relatively constant, and that for $M_\infty = 0.75$, ΔC_p increases slightly with increasing values of W_a/W_t. At the same time, the level in the diffuser decreased. Remembering that only the overall rms levels are being considered and that $M_\infty = 0.75$ is a critical Mach number, the increase of ΔC_p with W_a/W_t is most likely a result of the aeroacoustic resonance previously suggested. The reduction of ΔC_p in the diffuser is considered to be indicative of improved flow conditions downstream of the test section when plenum suction is used.

The evaluation of the influence of total temperature on the dynamic environment is shown in Fig. 14 for T_t = 100, 125, and 150°F. It was

found that with the exception of a significant variation on the test section wall at $M_\infty = 0.75$, the fluctuating pressures were not influenced by total temperature.

A comparison of data obtained from the PWT 16-ft tunnel, PWT 4-ft tunnel, and the MSFC 14-in. tunnel is presented in Fig. 15. Note that the levels in all tunnels fall within the range of $0.5 < \Delta C_p < 2.5$ percent and that the Tunnel 16T levels indicated from the present study are in very good agreement with the previous levels reported in Ref. 2. Figure 15 also indicates that both Tunnel 4T (Ref. 3) and Tunnel 16T have a critical Mach number range. If the sources of these disturbances could be eliminated, a considerable improvement in the fluctuating environment in these two tunnels would be realized.

The evaluation of the fluctuating environment in a wind tunnel inevitably leads to the question of what can be considered as acceptable. The satisfactory answer to this question requires that the measurement and analysis techniques be selected and analyzed and that a suitable criterion be applied. Unfortunately, however, although the measurement and analysis techniques can be readily analyzed at this time, a criterion for the evaluation of wind tunnel fluctuating environments does not exist. Thus the only recourse is to perform a relative evaluation with other tunnels, such as in Fig. 15. Based on Fig. 15, it appears that a value of $\Delta C_p = 0.5$ percent might be considered as a practical lower boundary for a criterion at this time.

SECTION V
CONCLUSIONS

The fluctuating pressures throughout the Tunnel 16T circuit have been measured and evaluated. The test section levels were found to be in agreement with the levels previously reported in Ref. 2. It was concluded that in the test section:

1. A critical Mach number range exists between 0.70 and 0.80. Maximum levels of $\Delta C_p = 3.5$ percent were measured in the test section free stream.
2. The compressor was not a direct influence on the levels in this critical Mach number range.
3. The influence of total pressure was found to be one of decreasing values of ΔC_p with increasing total pressure.

4. There was no significant variation of ΔC_p with total temperature.

5. The levels in Tunnel 16T compare favorably with the levels in Tunnel 4T and the MSFC 14-in. tunnel.

REFERENCES

1. Chevalier, H. L. and Todd, H. E. "Measurement of the Pressure Fluctuations in the Test Section of the 16-Foot Transonic Circuit in the Frequency Range from 5 to 1000 cps." AEDC-TN-61-51 (AD255763), May 1961.

2. Riddle, C. D. "Investigation of Free-Stream Fluctuating Pressures in the 16-ft Tunnels of the Propulsion Wind Tunnel Facility." AEDC-TR-67-167 (AD818388), August 1967.

3. Credle, O. P. "An Evaluation of the Fluctuating Airborne Environment in the AEDC-PWT 4-ft Transonic Tunnel." AEDC-TR-69-236, November 1969.

4. Boone, J. R. and McCanless, G. F. "Application of the Techniques for Evaluating the Acoustic Sources of Background Noise in Wind Tunnel Facilities." Technical Report HSM-R05-69.

5. Test Facilities Handbook (Eighth Edition). "Propulsion Wind Tunnel Facility, Vol. 5." Arnold Engineering Development Center, December 1969.

6. Morse, P. M. and Ingard, K. U. Theoretical Acoustics. McGraw Hill, Inc., New York, 1968.

APPENDIX
ILLUSTRATIONS

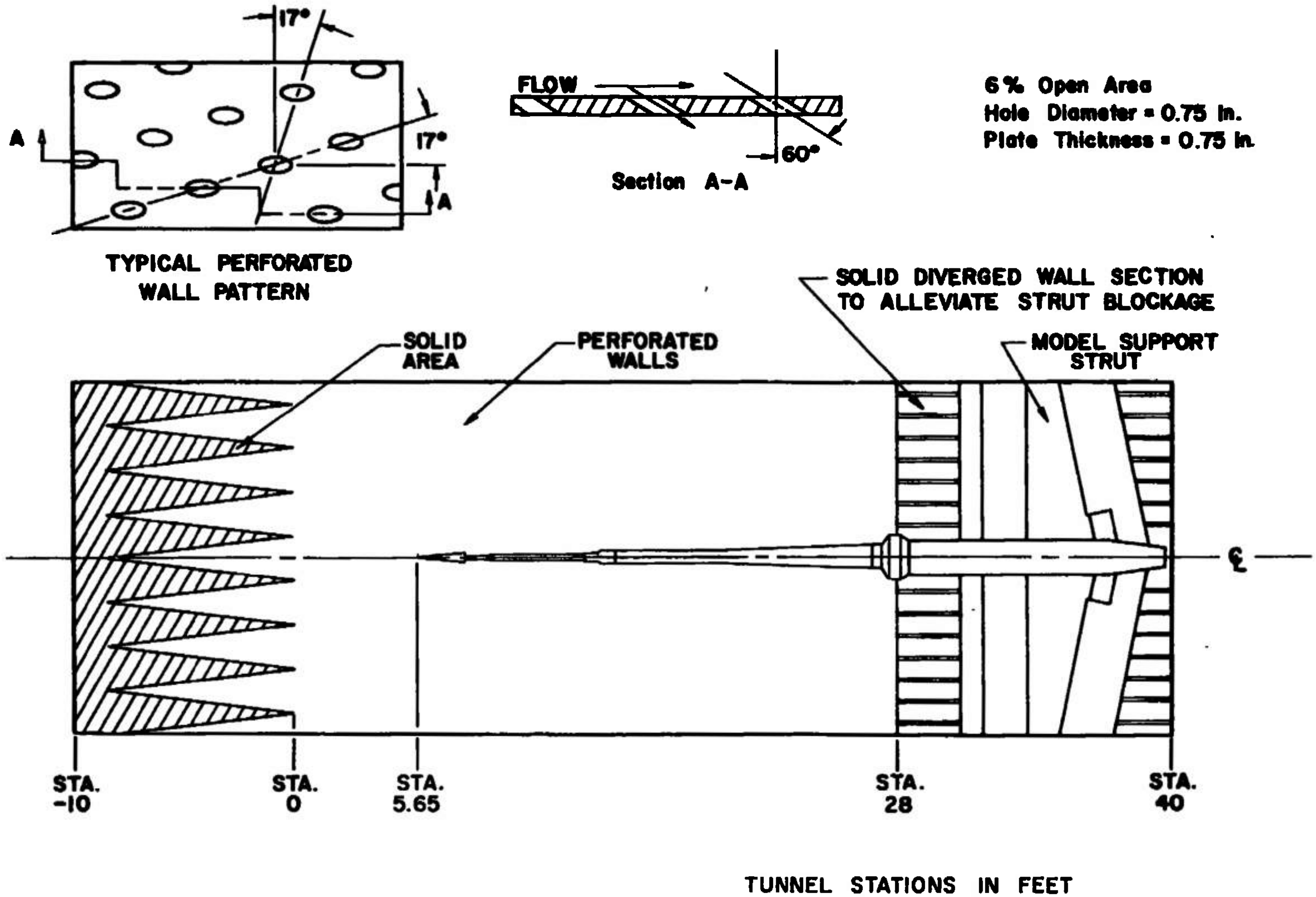


Fig. 1 Tunnel 16T Test Section and Perforated Wall Details, 10-deg Cone Installed

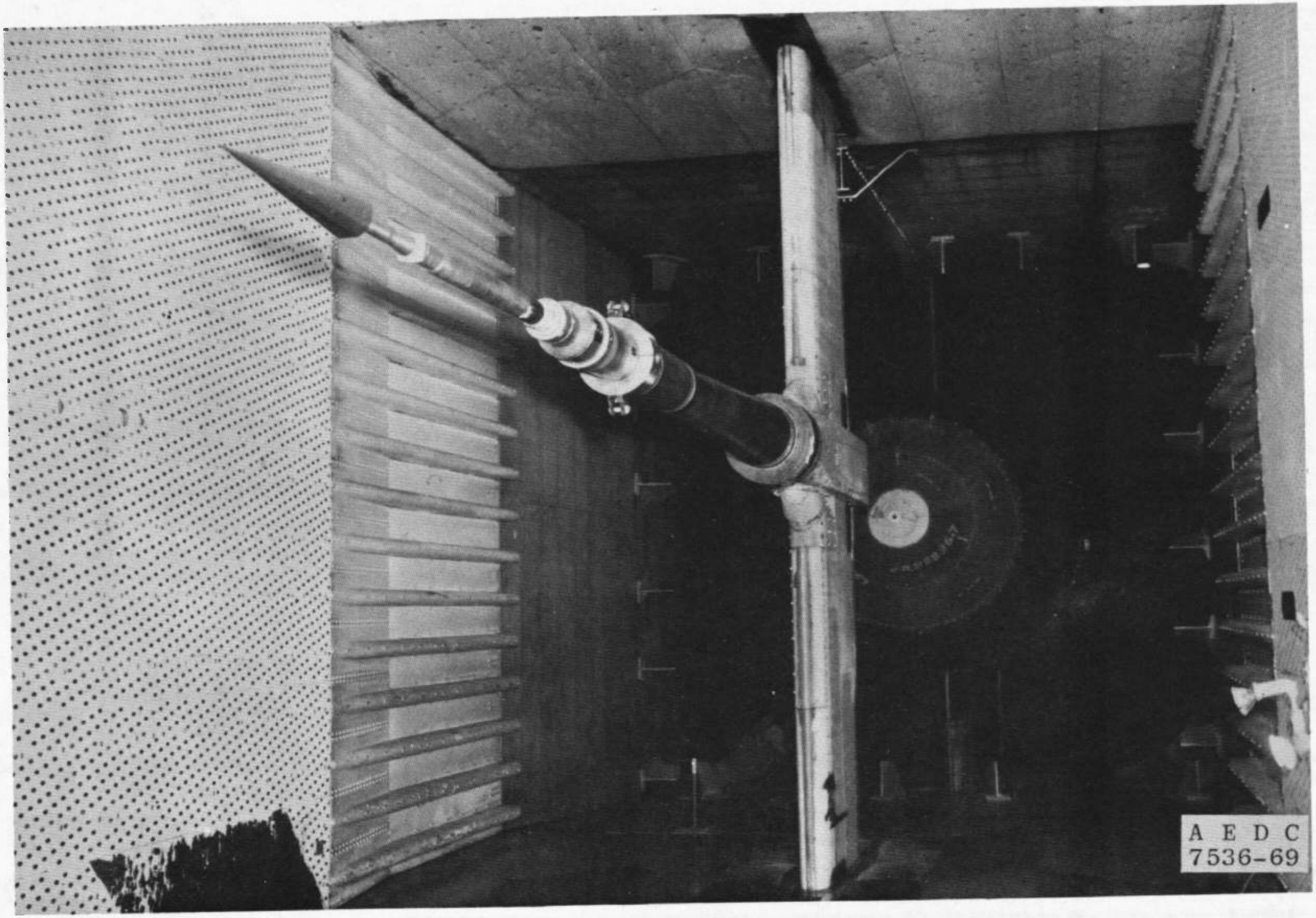
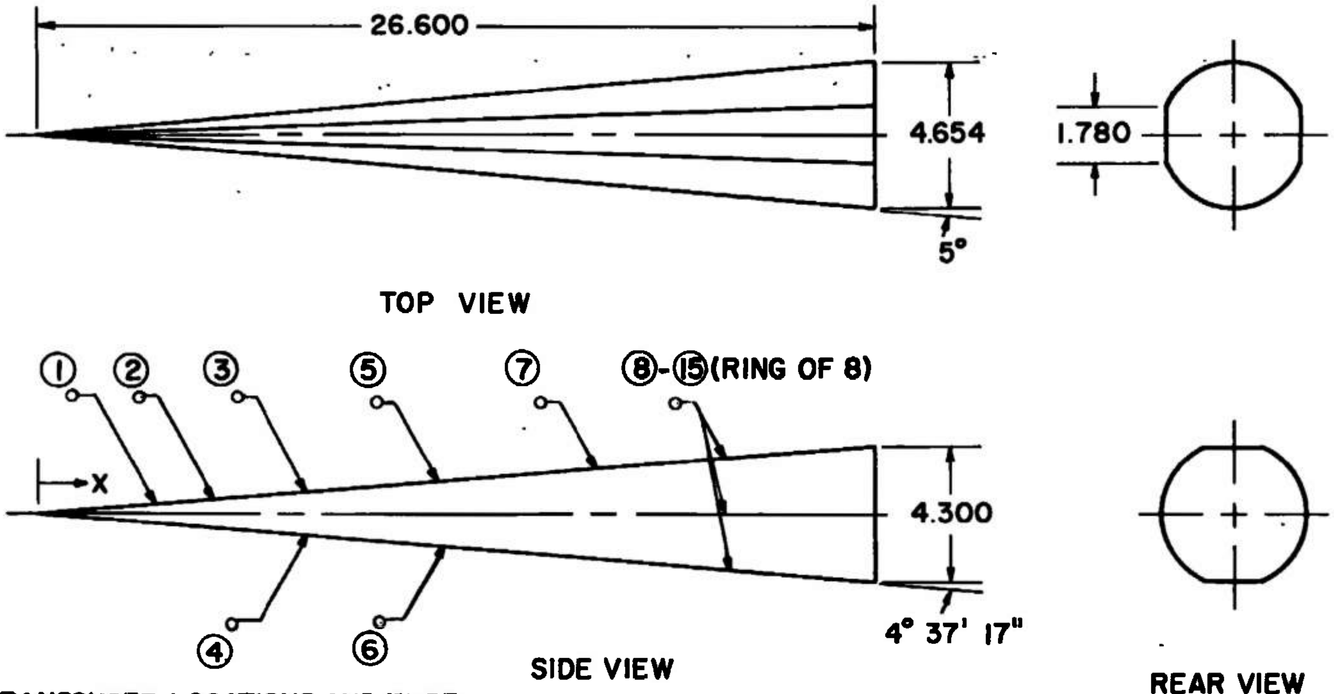


Fig. 2 Photograph of 10-deg Cone Installation



TRANSDUCER LOCATIONS AND TYPE

TRANSDUCER	X	TYPE
1	1.88	BYTREX
2	2.50	KULITE
3	5.00	BYTREX
4	5.00	KULITE
5	7.50	KULITE
6	13.30	KISTLER
7	17.90	BYTREX
8-15	19.90	KULITE

ALL DIMENSIONS IN INCHES

Fig. 3 Schematic of 10-deg Cone and Transducer Details

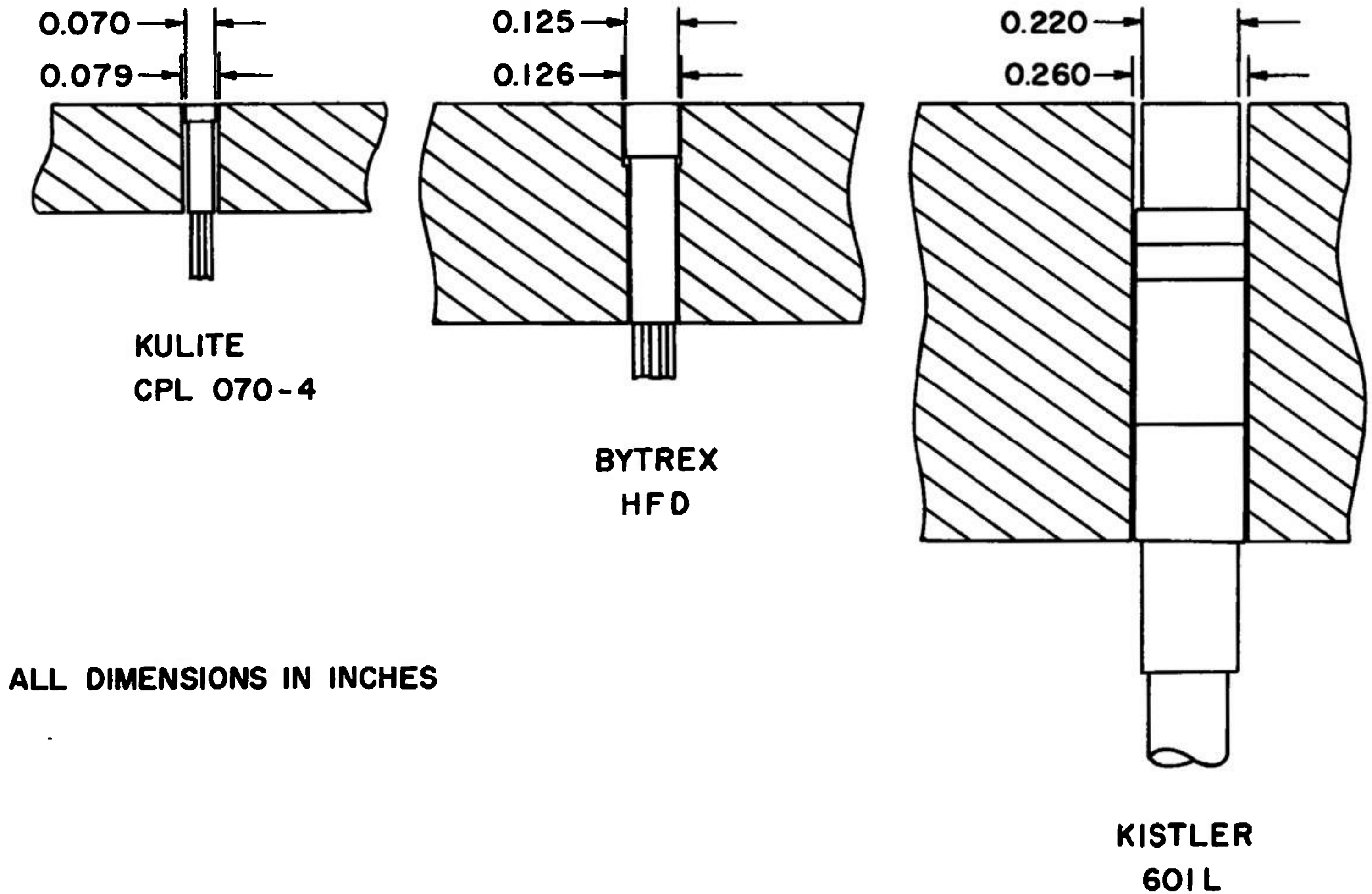


Fig. 4 Typical Installation of 10-deg Cone Transducers

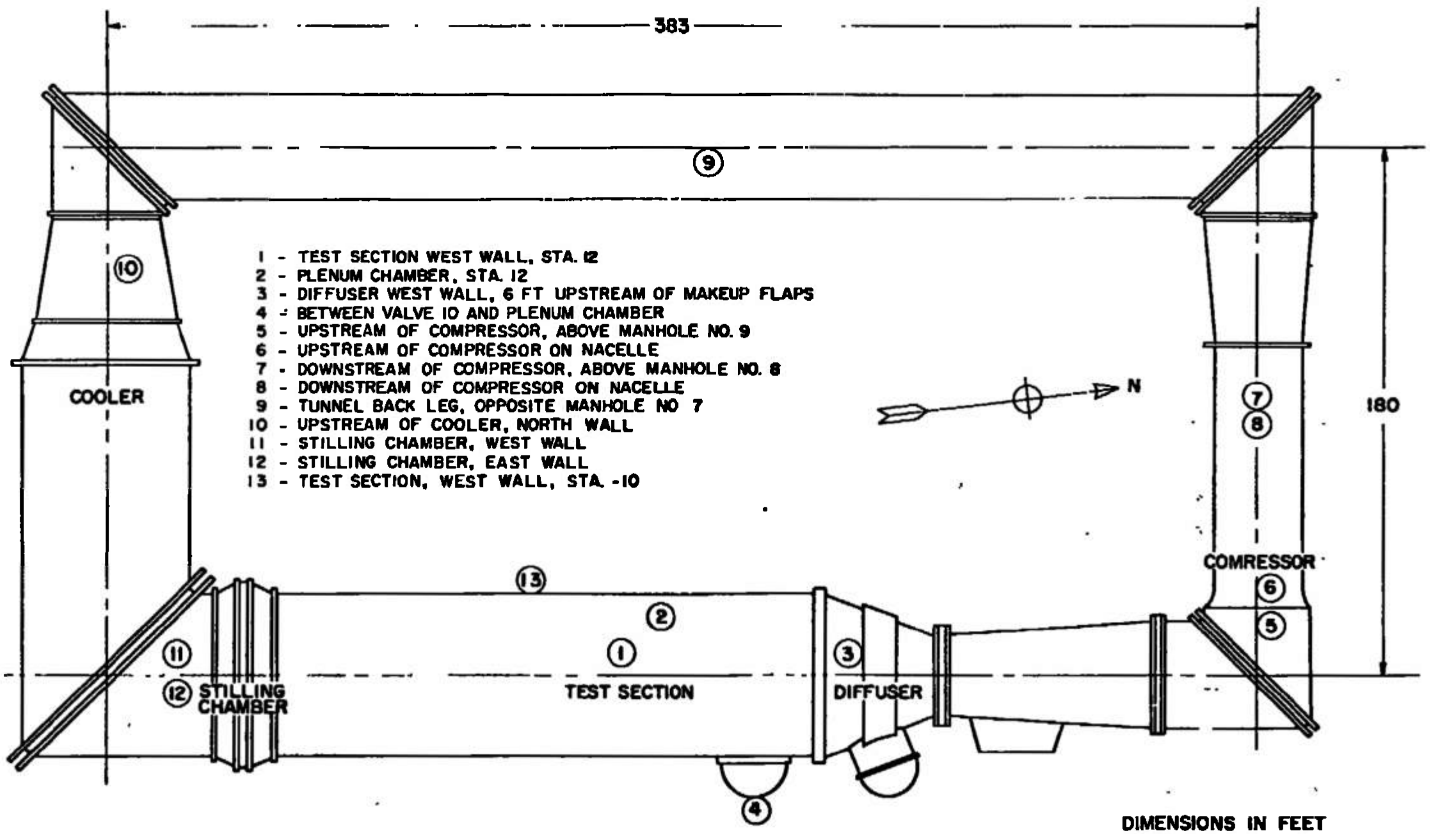
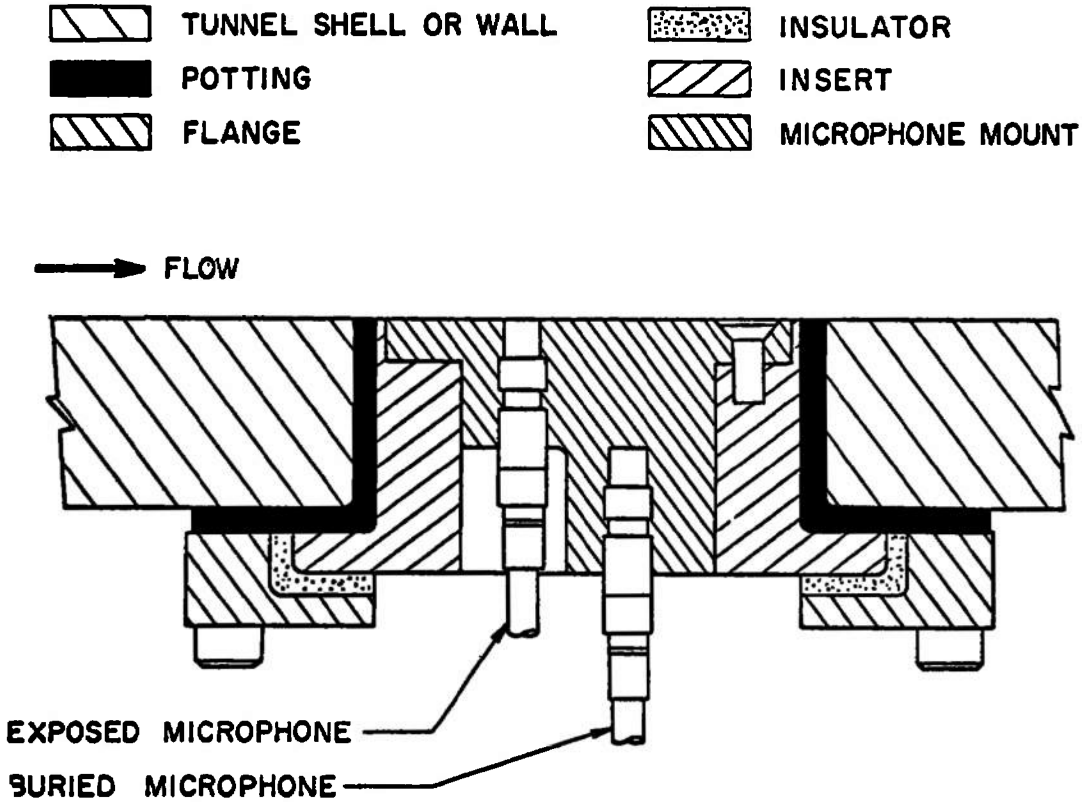
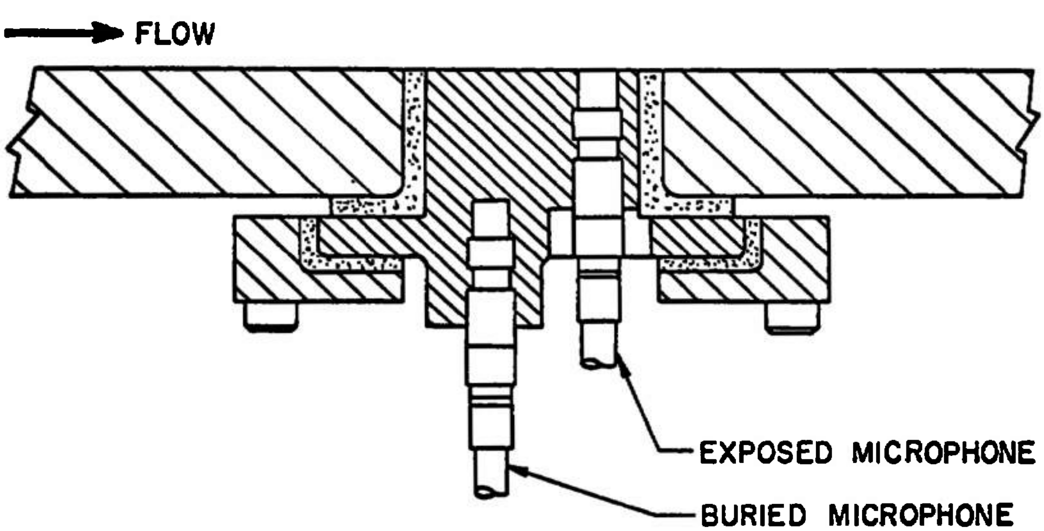


Fig. 5 Tunnel 16T Circuit, Microphone Locations



a. Tunnel Shell



b. Test Section Wall and Compressor Nacelle

Fig. 6 Mounting Arrangement for Tunnel Circuit Microphones

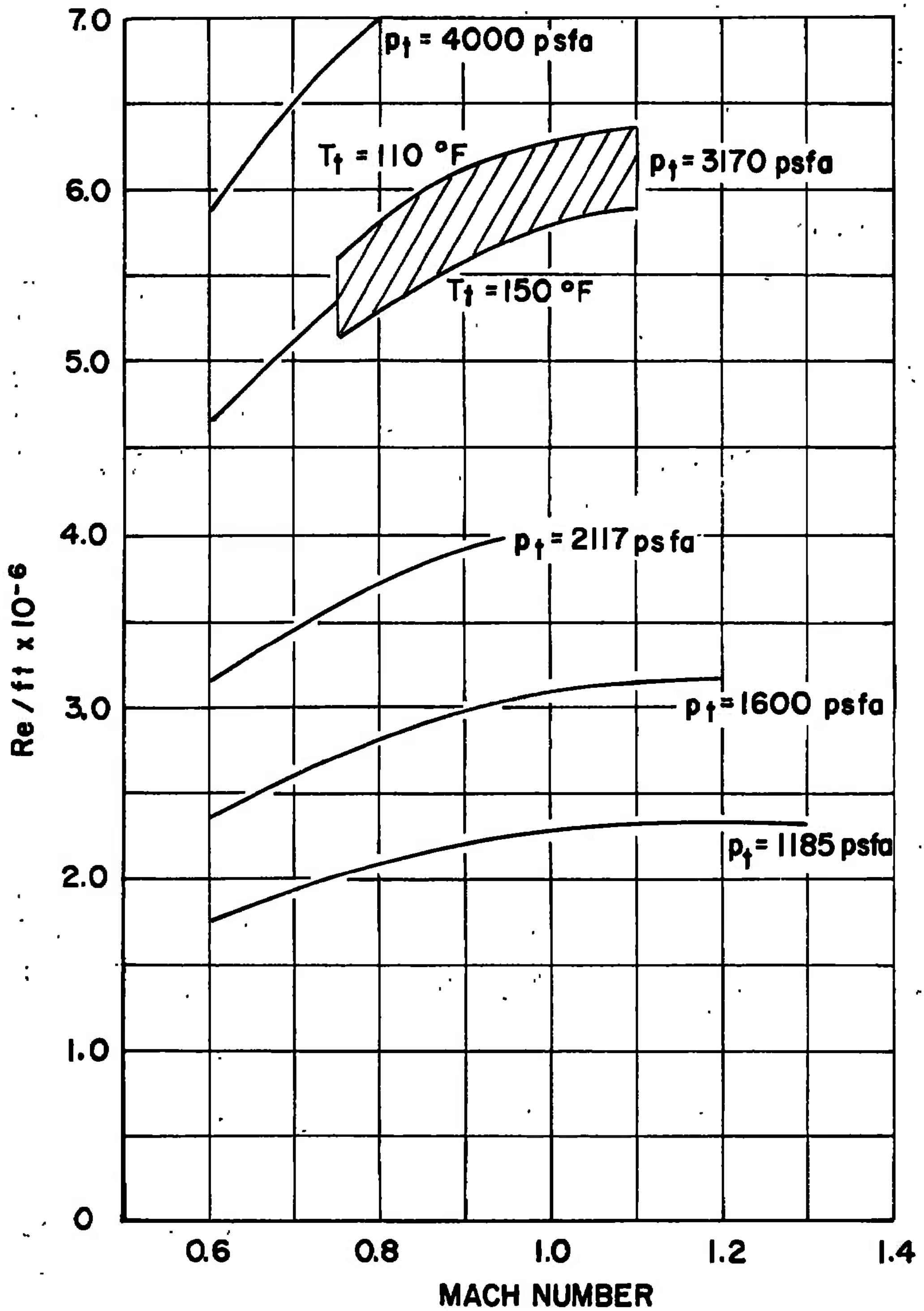


Fig. 7 Variation of Reynolds Number with Mach Number

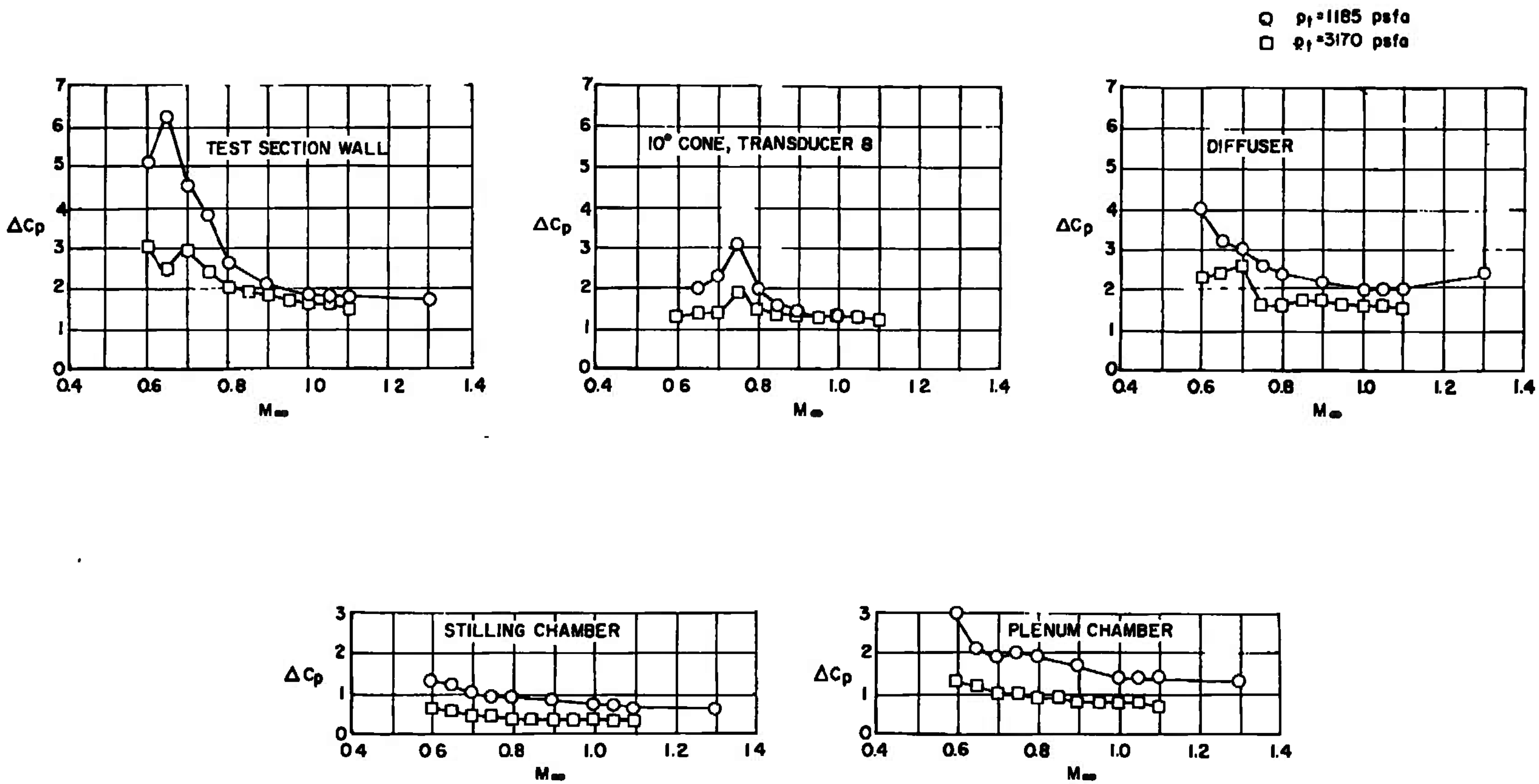


Fig. 8 Evaluation of Mach Number Effects

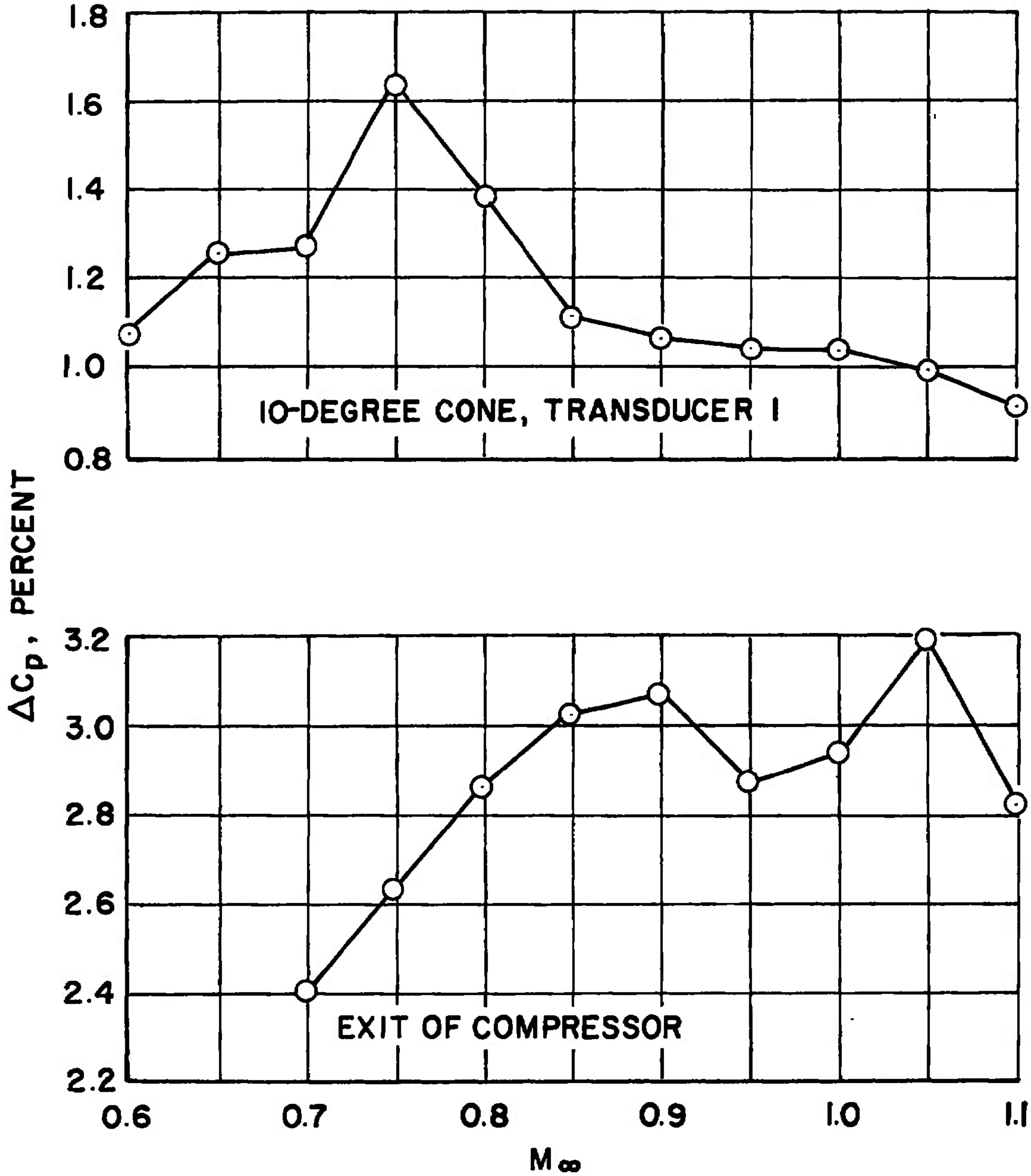


Fig. 9 Comparison of Compressor and Test Section Fluctuating Pressure Levels, p_t = 3170 psfa

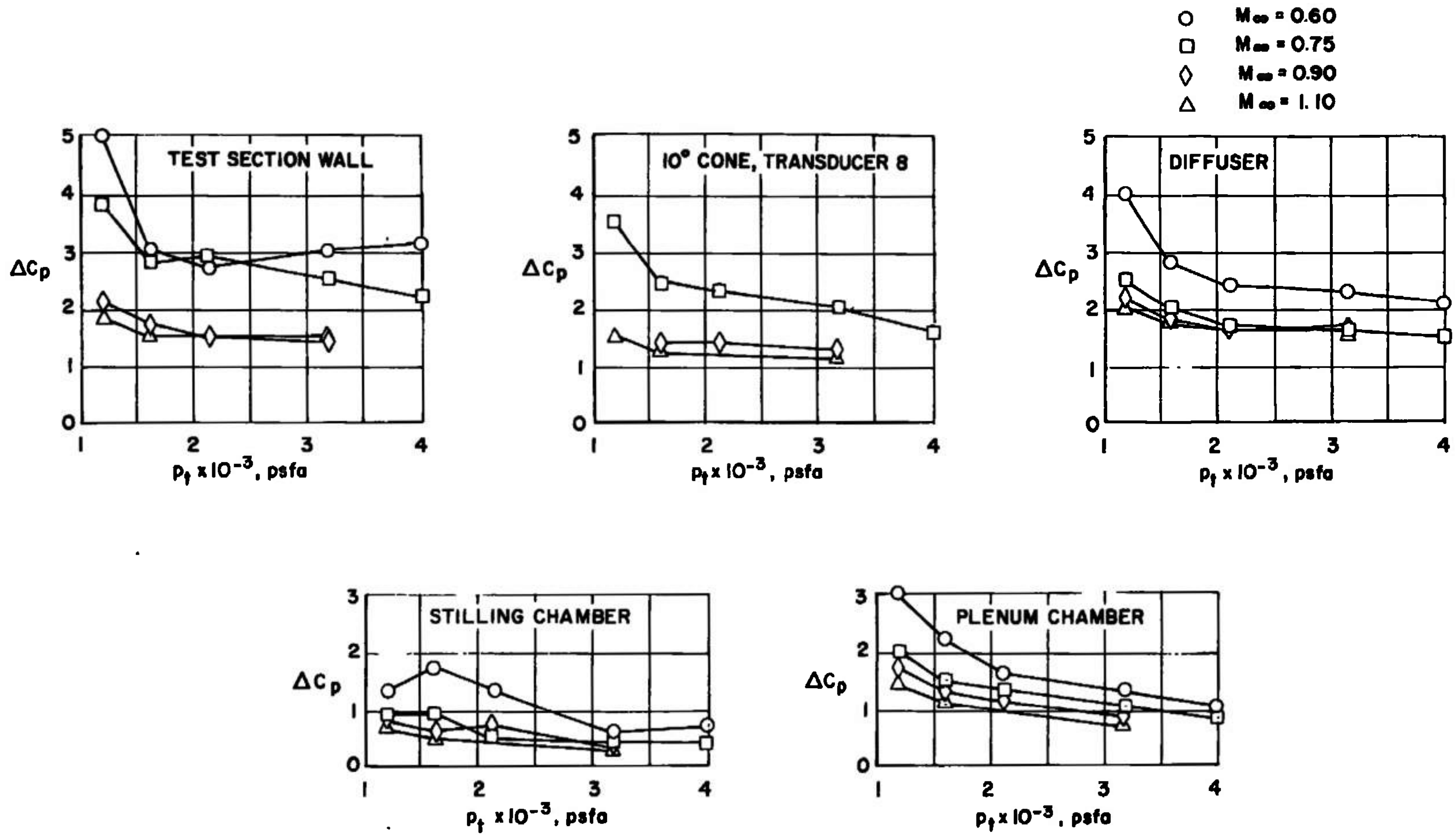


Fig. 10 Evaluation of Total Pressure Effects

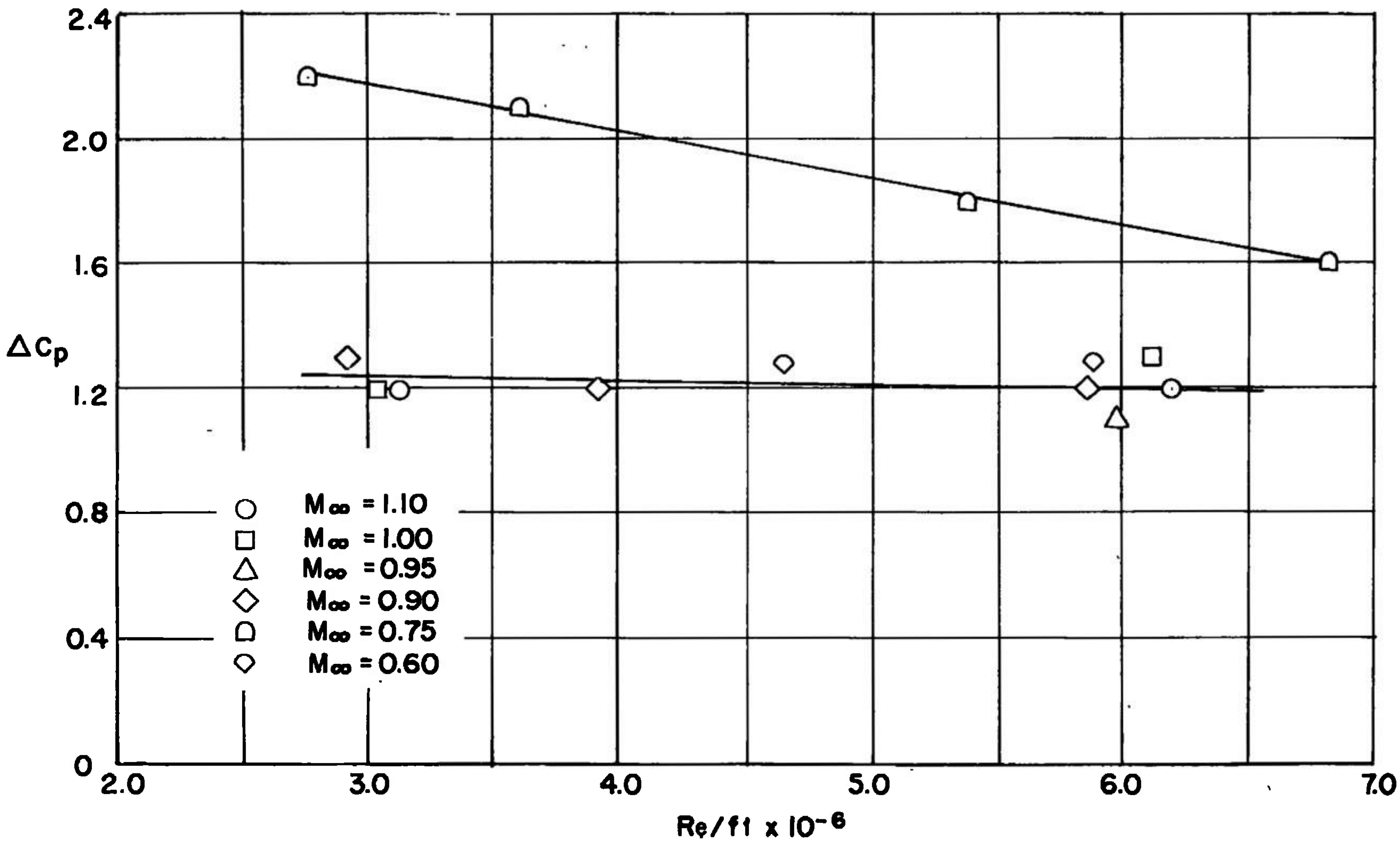


Fig. 11 Variation of ΔC_p versus Re/ft on 10-deg Cone, Transducer 8

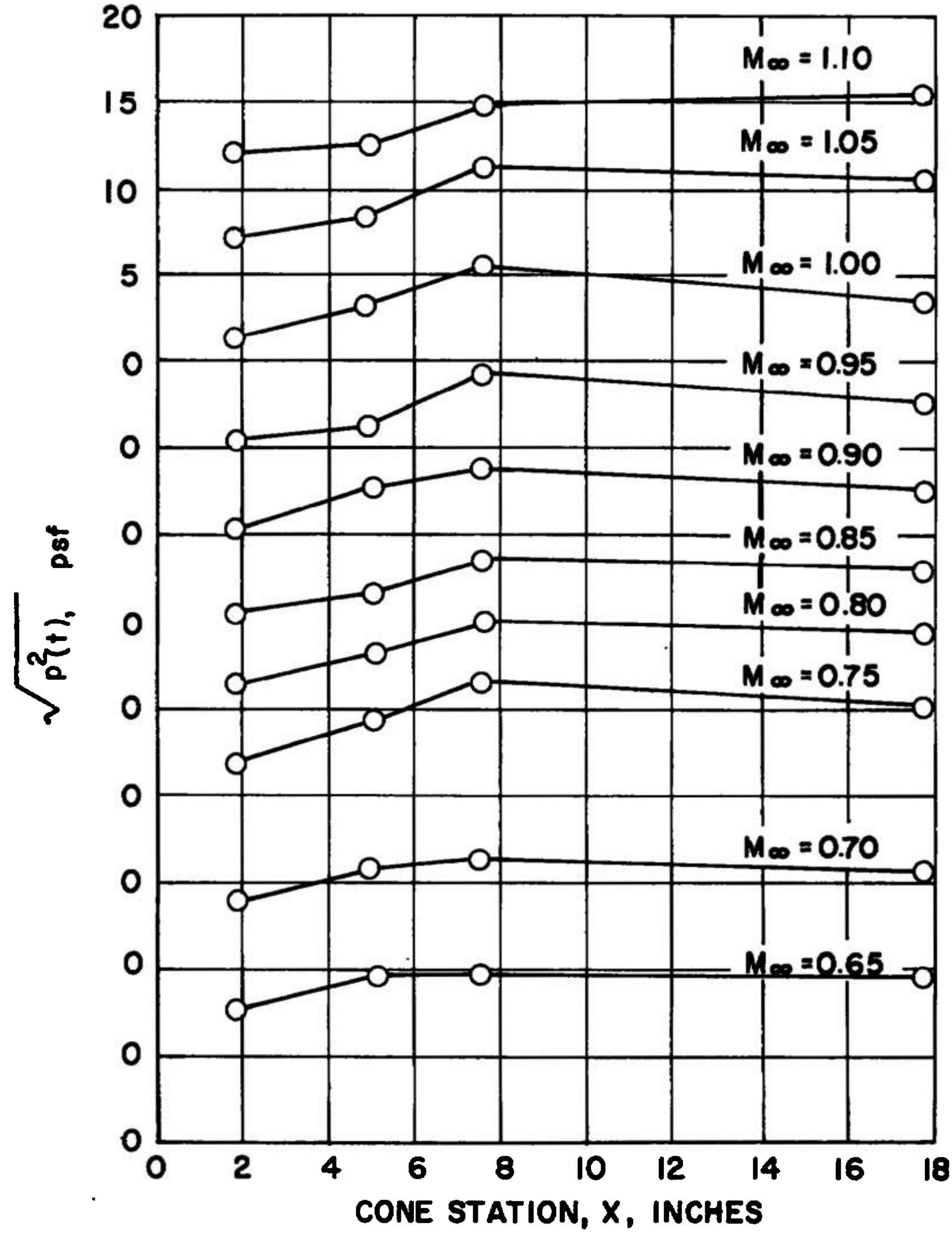


Fig. 12 Evaluation of 10-deg Cone Measurements, p_t = 3170 psfa

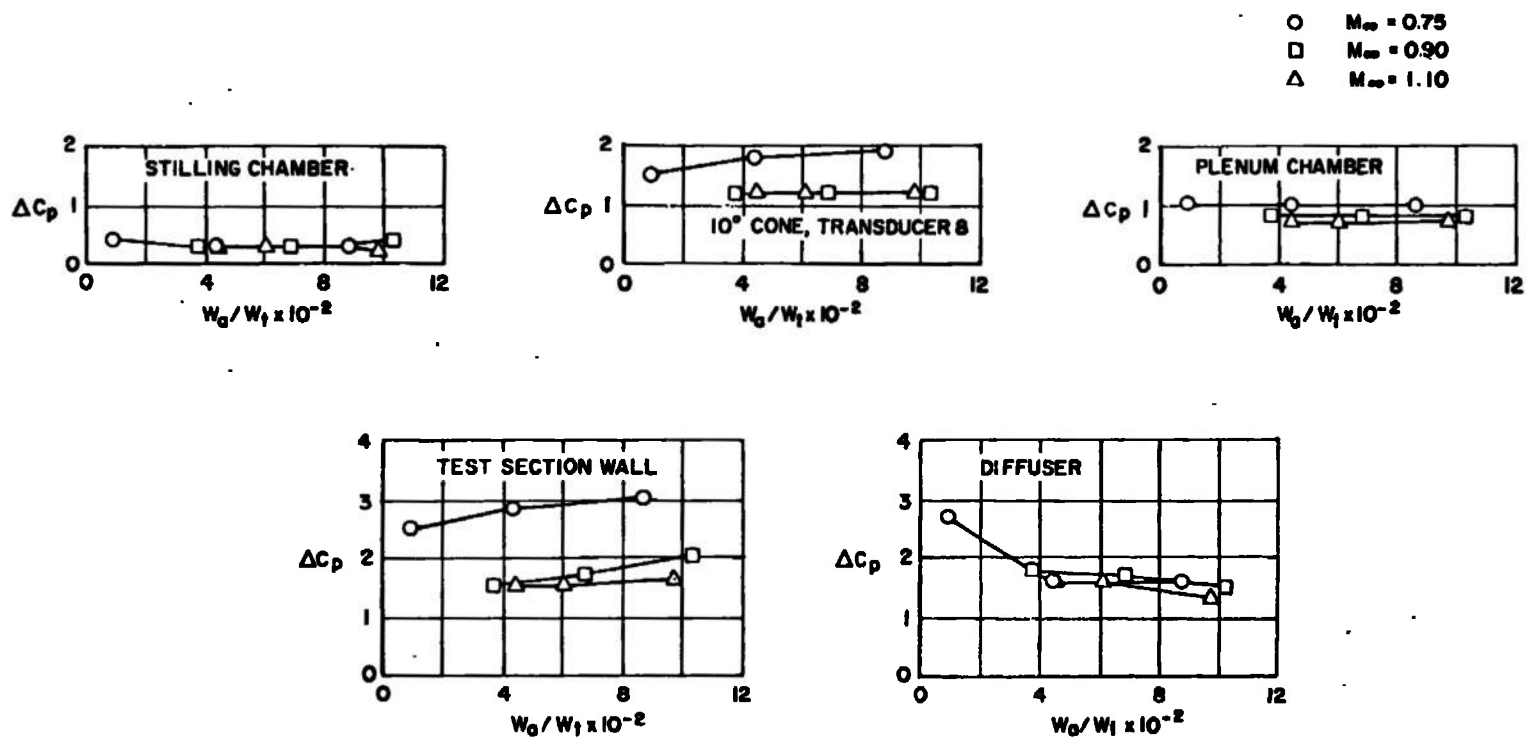


Fig. 13 Evaluation of Plenum Suction Effects, p_t = 3170 psfa

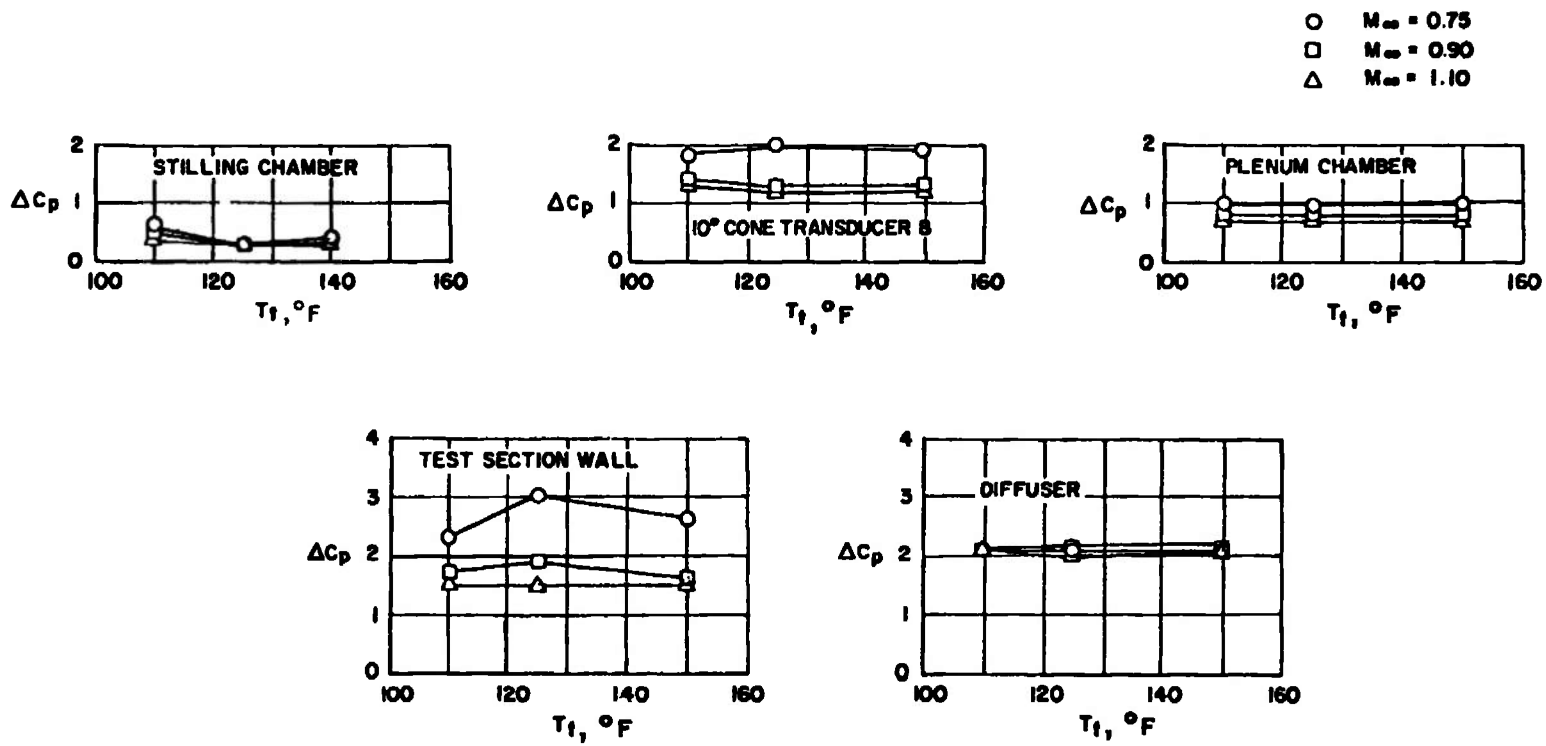


Fig. 14 Evaluation of Total Temperature Effects, p_t = 3170 psfa

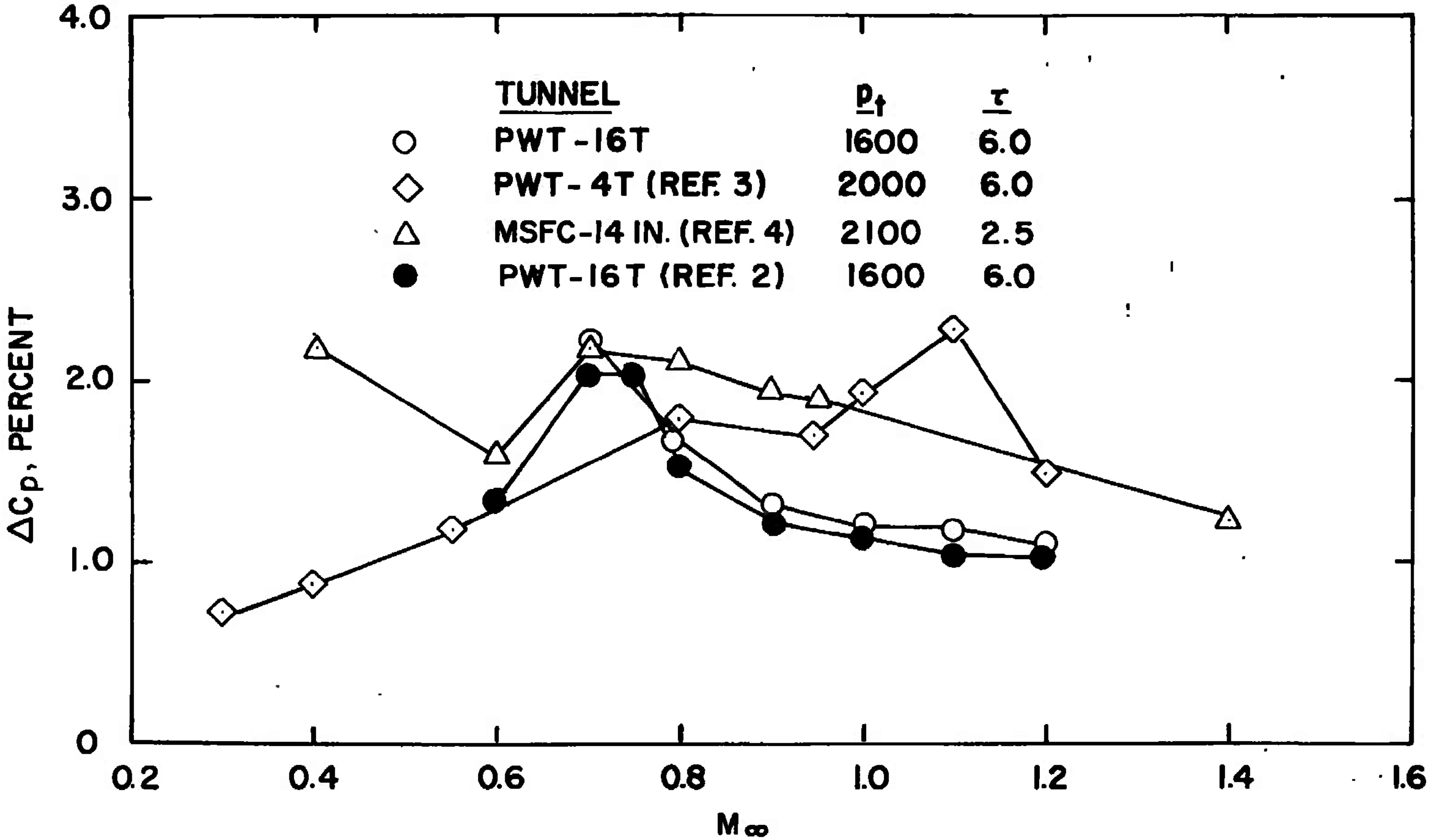


Fig. 15 Comparison of Fluctuating Pressures in the Test Section of Transonic Tunnels as Measured on the Aft Portion of a 10-deg Cone

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*	2a. REPORT SECURITY CLASSIFICATION
Arnold Engineering Development Center, ARO, Inc., Operating Contractor, Arnold Air Force Station, Tennessee 37389	UNCLASSIFIED
	2b. GROUP: N/A

3. REPORT TITLE

EVALUATION OF THE OVERALL ROOT-MEAN-SQUARE FLUCTUATING PRESSURE LEVELS IN THE AEDC PWT 16-FT TRANSONIC TUNNEL

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

September 9 to 10, 1969 - Final Report

This document has been approved for public release its distribution is unlimited.

5. AUTHOR(S) *(First name, middle initial, last name)*

O. P. Credle and T. O. Shadow, ARO, Inc.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
February 1970	32	6

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
F40600-69-C-0001	AEDC-TR-70-7
b. System 921E	
c.	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d.	N/A

10. DISTRIBUTION STATEMENT ~~This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of Arnold Engineering Development Center (AETS), Arnold Air Force Station, Tennessee 37389.~~

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
Available in DDC.	NASA, Marshall Space Flight Center, Huntsville, Alabama 35812

13. ABSTRACT

An investigation was conducted to evaluate the fluctuating pressures in the AEDC PWT 16-ft transonic wind tunnel circuit. Test results were obtained over a Mach number range from 0.6 to 1.3 and a unit Reynolds number range from 1.8 to 6.8 million. The influence of Mach number, total pressure, total temperature, and (auxiliary) plenum suction on the test section fluctuating pressures was determined. In addition, a comparison of the Tunnel 16T fluctuating pressures with those of the AEDC PWT 4-ft transonic tunnel and the NASA-Huntsville 14-in. transonic tunnel is made. A critical Mach number range was defined near a Mach number of 0.75. The maximum root-mean-square fluctuating pressure in the test section was 3.5 percent of the free-stream dynamic pressure in the critical Mach number range. The source of this maximum fluctuating pressure did not appear to be controlled by the compressor. The free-stream fluctuating pressure was found to vary inversely with the total pressure and to be relatively invariant with total temperature and auxiliary plenum suction.

~~This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of Arnold Engineering Development Center (AETS), Arnold Air Force Station, Tennessee 37389.~~

DD FORM 1 NOV 65 1473

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
transonic wind tunnels -- Pressure Levels						
-- PWT						
pressure -- Pressure Levels						
variations						
perturbation						
subsonic flow						
supersonic flow # 17-3						

AFSC
Arnold AFS Tenn